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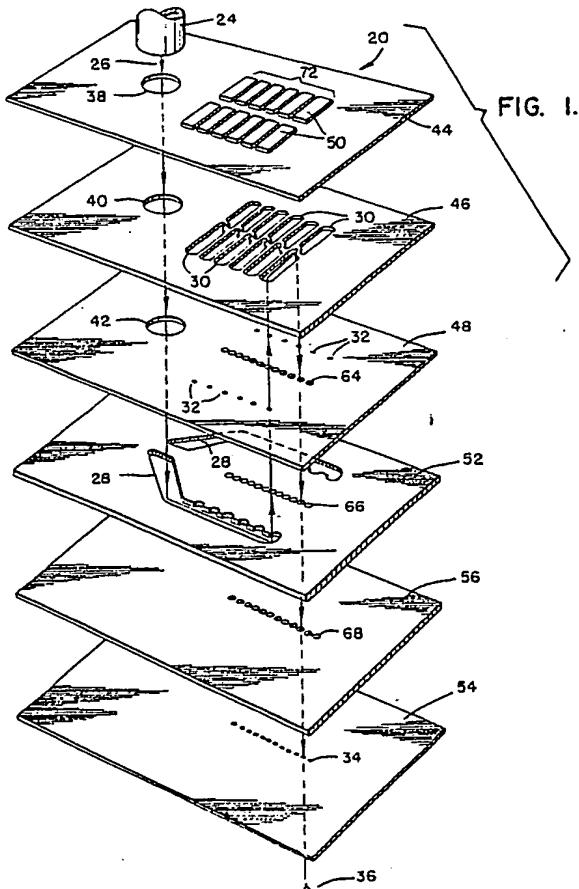
(56) Documents cited

GB A 2134853	GB A 2094233
GB A 2134852	EP 0100624
GB A 2115748	EP 0063637
GB A 2104453	US 4544932

(58) Field of search  
B6F

**(54) Impulse ink jet print head and methods of making the same**

(57) An impulse ink jet print head and method of fabricating same are disclosed. The print head comprises a plurality of superposed, contiguous plates (22) including a nozzle plate (54) with at least a pair of nozzles (34) for ejecting ink droplets in a direction perpendicular to a plane of the plates. Another plate is a channel plate (46) defining at least a pair of coplanar axially aligned elongated chambers (30), each connected to an ink supply and having an outlet (64) communicating with an associated nozzle (34). A diaphragm plate (44) overlies the channel plate (46) and has transducers (50) thereon for displacing ink in each of the chambers (30) to eject discrete ink droplets from the nozzles. Other plates may include a manifold plate (52) for directing ink to a plurality of pairs of chambers and a restrictor plate (48) with restrictor orifices positioned between the manifold plate and each of the chambers. The method of fabricating the print head includes forming the different plates, forming the transducers, and assembling all of the components in a particular relationship.



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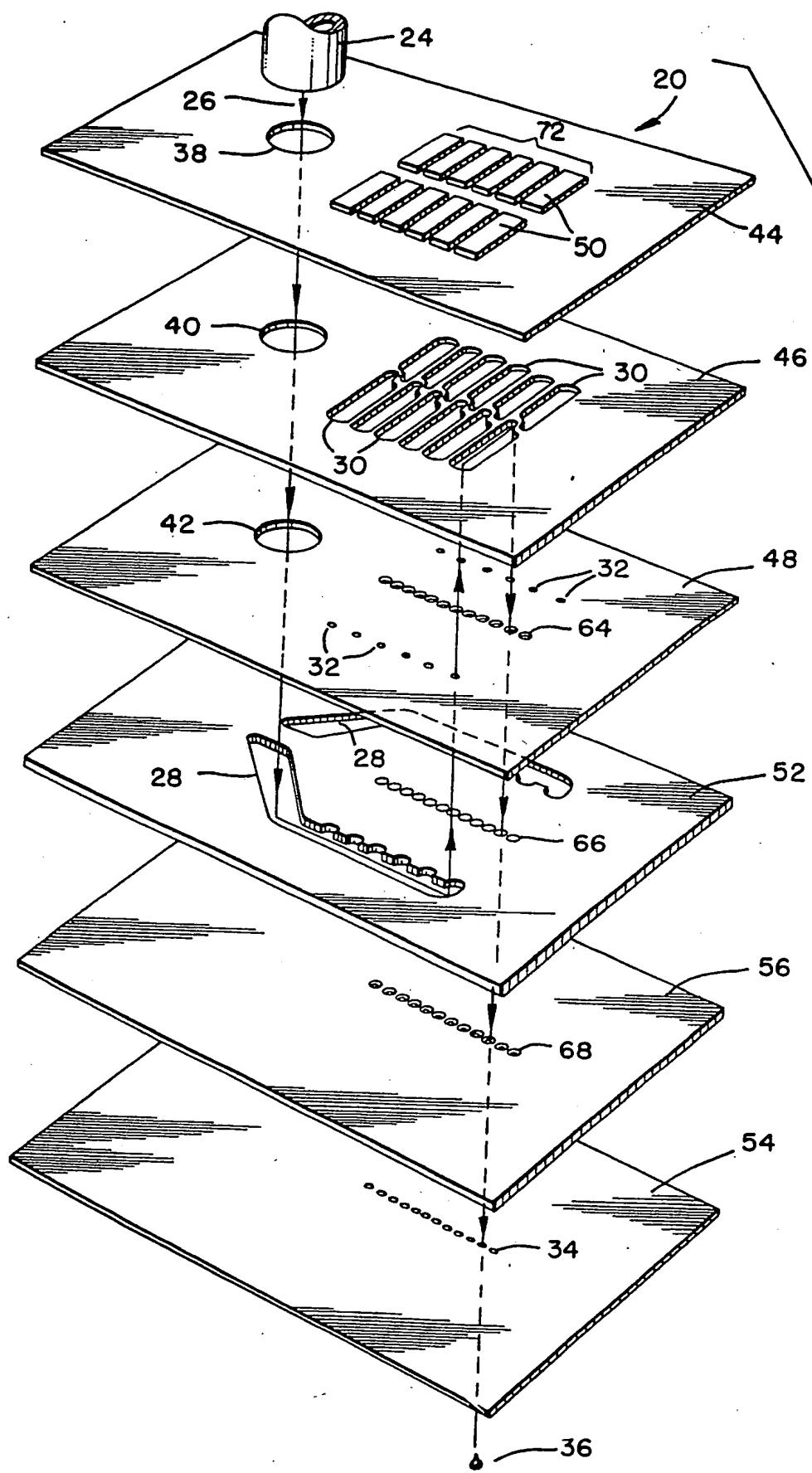


FIG. 1.

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FIG. 2.

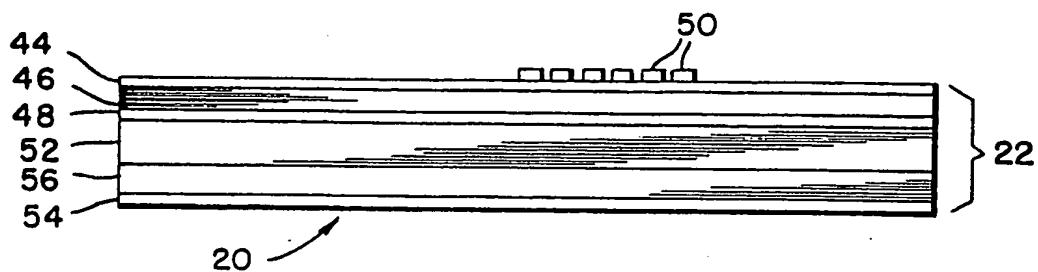


FIG. 3.

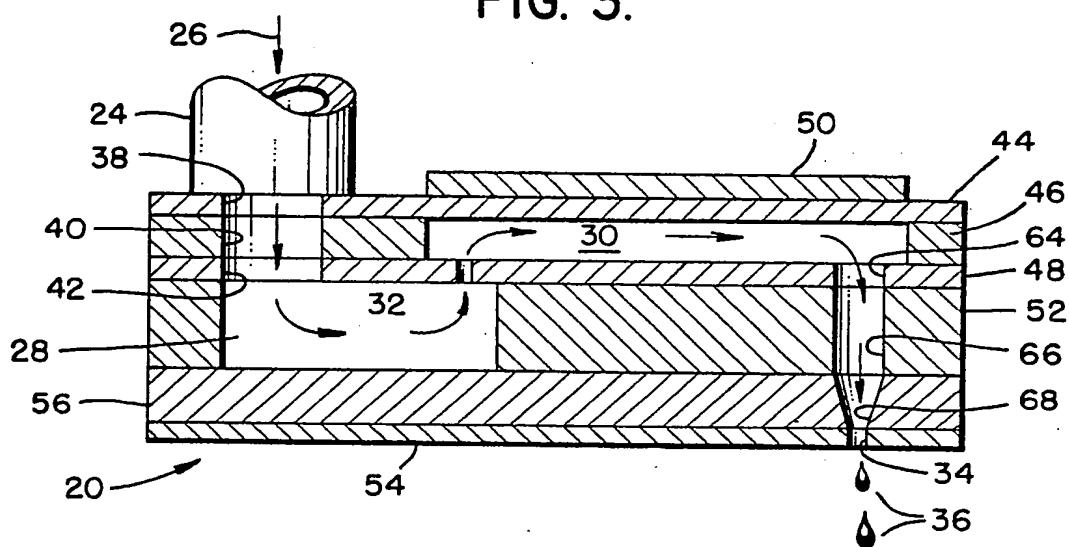


FIG. 5.

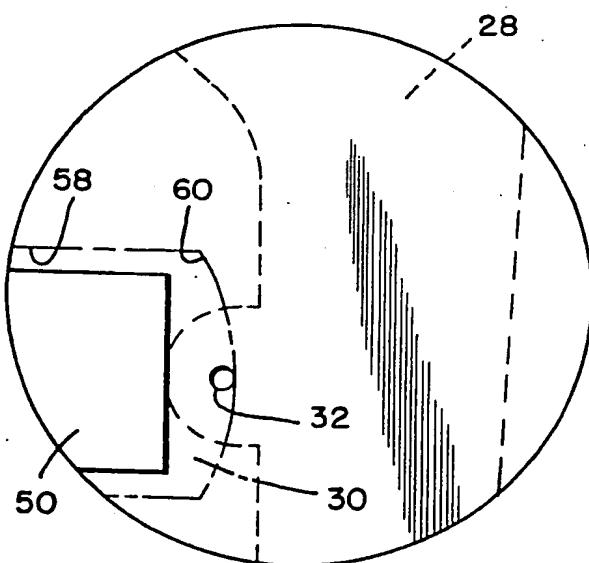


FIG. 6.

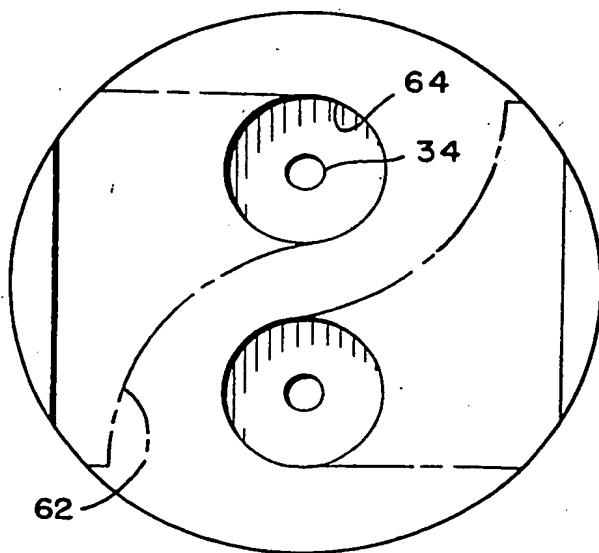
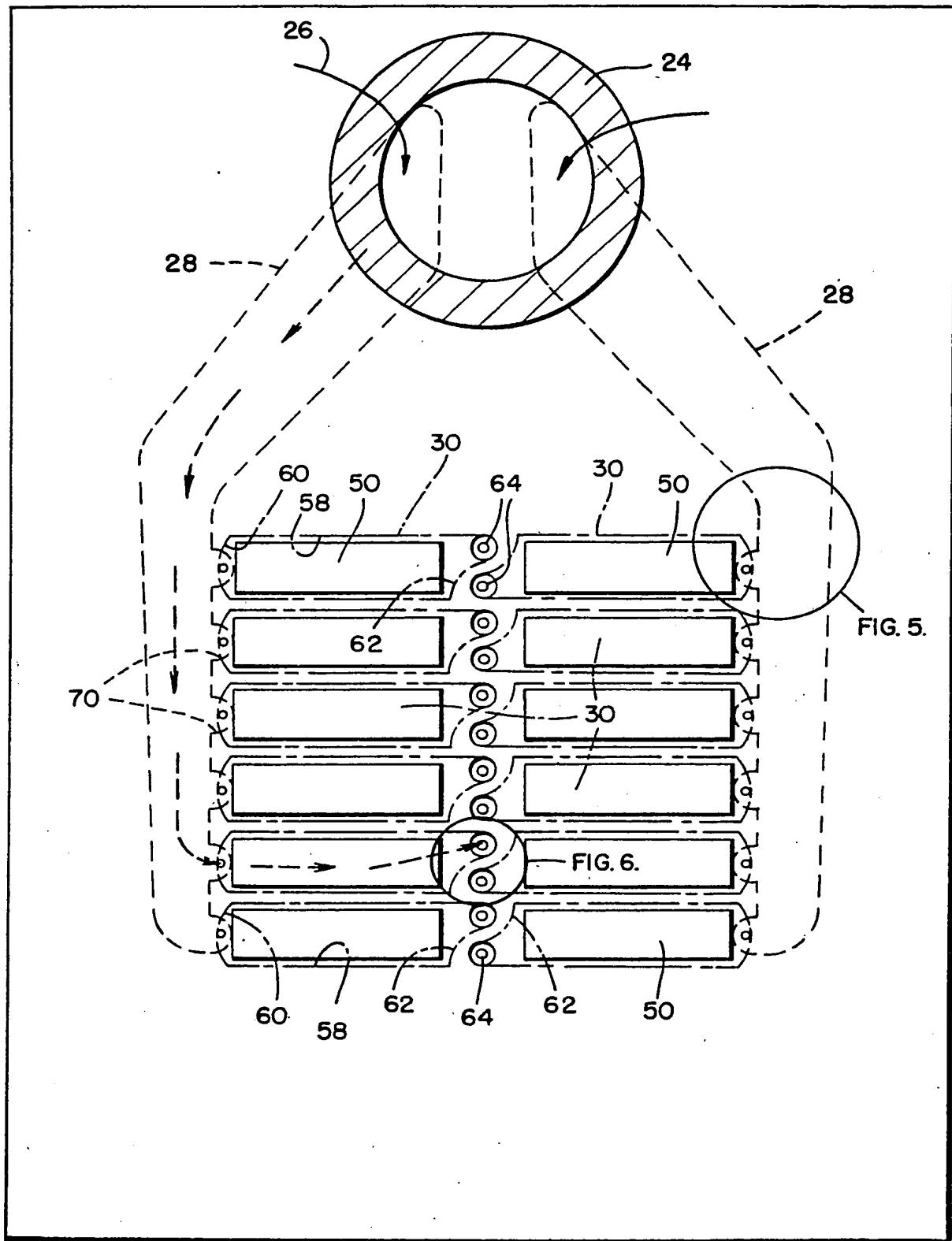


FIG. 4.



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FIG. 7.

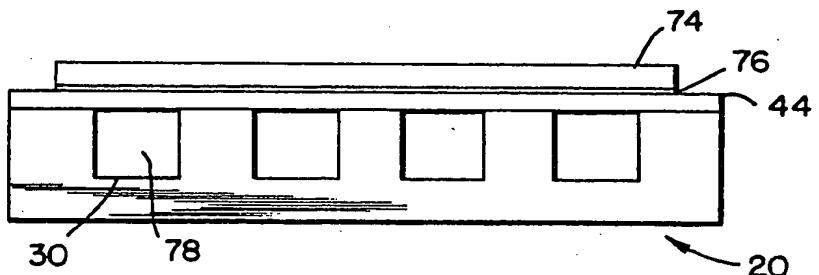


FIG. 8.

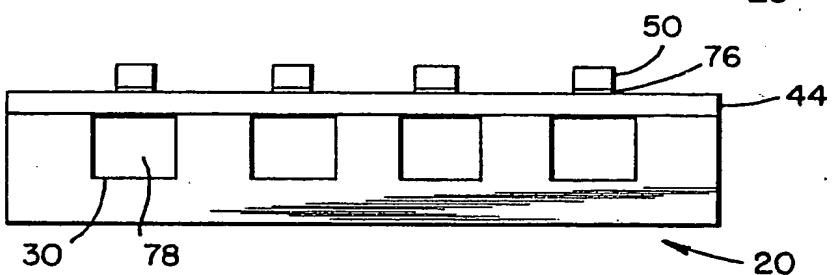


FIG. 9.

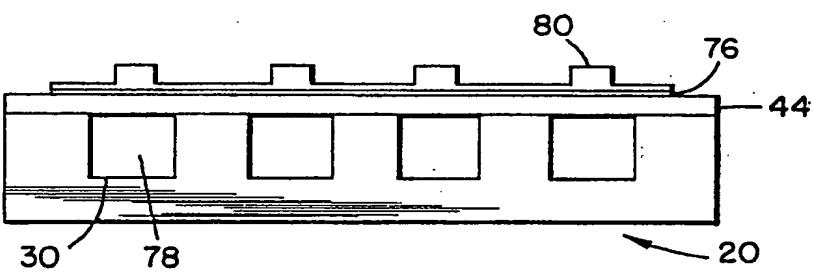
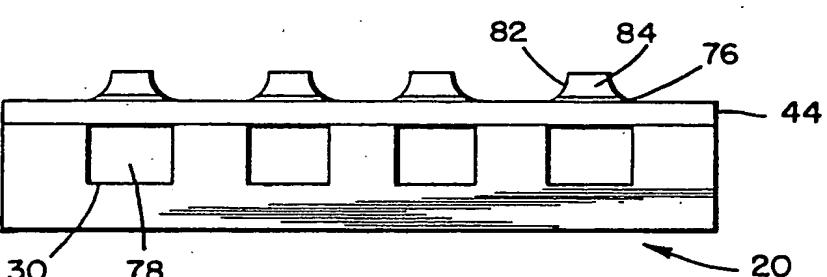


FIG. 10.



## SPECIFICATION

### Impulse ink jet print head and methods of making the same

5 This invention relates to an impulse ink jet print head and to a method of fabricating such print heads, and in particular though not exclusively, to an impulse ink print jet comprising a plurality of plates held together in a superposed contiguous relationship.

Ink jet systems, and particularly impulse ink jet systems, are well known in the art. The principle behind an impulse ink jet as embodied in the present invention is the displacement of ink and the subsequent emission of ink droplets from an ink chamber through a nozzle by means of a driver mechanism which consists of a transducer (e.g., of piezoceramic material) bonded to a thin diaphragm. When a voltage is applied to the transducer, the transducer attempts to change its planar dimensions, but because it is securely and rigidly attached to the diaphragm, bending occurs. This bending displaces ink in the chamber, causing outward flow both through an inlet from the ink supply, or restrictor, and through an outlet or nozzle. The relative fluid impedances of the resistor and nozzle are such that the primary outflow is through the nozzle. Refill of the ink chamber after a droplet emerges from the nozzle results from the capillary action of the ink meniscus within the nozzle which can be augmented by reverse bending of the transducer. Time for refill depends on the viscosity and surface tension of the ink as well as the impedance of the fluid channels. A subsequent ejection will then occur but only when refill has been accomplished and when, concurrently, the amplitude of the oscillations resulting from the first ejection have become negligible. Important measures of performance of an ink jet are the response of the meniscus to the applied voltage and the recovery time required between droplet ejections having uniform velocity and drop diameter.

In general, it is desirable to employ a geometry that permits several nozzles to be positioned in a densely packed array. In such an array, however, it is important that the individual nozzles eject ink droplets of uniform diameter and velocity even at varying droplet ejection rates.

Some representative examples of the prior art will now be described. U.S. Patent 3,107,630 to Johnson et al is an early disclosure of the use of piezoceramic transducers being utilized to produce a high frequency cyclic pumping action. This was followed by U.S. Patent 3,211,088 to Naiman which discloses the concept of an impulse ink jet print head.

According to Naiman, when a voltage is applied to a transducer, ink is forced through the nozzle to form a spot upon a printing surface. The density of the spots so formed is determined by the number of nozzles employed in a matrix. Another variation of print head is disclosed in U.S. Patent 3,767,120 issued to Stemme which utilizes a pair of chambers positioned in series between the transducer and the discharge nozzle.

65 Significant improvements over the then existing

prior art are disclosed in a series of patents issued to Kyser et al, namely, U.S. Patents Nos. 3,946,398, 4,189,734, 4,216,483, and 4,339,763. According to each of these disclosures, fluid droplets are

- 70 projected from a plurality of nozzles at both a rate and in a volume controlled by electrical signals. In each instance, the nozzle requires that an associated transducer, and all of the components, lie in planes parallel to the plane of the droplets being ejected.
- 75 A more recent disclosure of an ink jet print head is provided in the U.S. Patent No. 4,525,728 issued to Koto. In this instance, the print head includes a substrate having a plurality of pressurization chambers of rectangular configuration disposed thereon. Ink supply passages and nozzles are provided for each pressurization chamber. Each chamber also has a vibrating plate and a piezoceramic element which cooperate to change the volume of the pressurization chamber to cause ink to be ejected from the respective nozzles thereof.
- 80 In many instances of the prior art, ink jet print heads are assembled from a relatively large number of discrete components. The cost of such a construction is generally very high. For example, an array of ink jets requires an array of transducers. Typically, each transducer is separately mounted adjacent to the ink chamber of each jet by an adhesive bonding technique. This presents a problem when the number of transducers in the
- 85 array is greater than, for example, a dozen, because complications generally arise due to increased handling complexities, for example, breakage or failure of electrical connections. In addition, the time and parts expense rise almost linearly with the
- 90 number of separate transducers that must be bonded to the diaphragm. Furthermore, the chances of a failure or a wider spread in performance variables such as droplet volume and speed, generally increase. Additionally, in many instances, prior art
- 95 print heads were large and cumbersome and could accommodate relatively few nozzles within the allotted space.
- 100 According to one aspect of this invention, there is provided an impulse ink jet print head comprising:
- 110 a plurality of operating plates held together in a superposed relationship including at least:
  - a first plate including a pair of nozzles therein for ejecting droplets of ink therethrough;
  - 115 a second plate defining a pair of generally coplanar axially aligned elongated ink chambers having relatively long sidewalls and relatively short endwalls, each of said chambers connected to an ink supply and having an outlet for directing ink toward an associated one of said nozzles in said first plate;
  - 120 each of said nozzles having a central axis extending transversely of the planes of said plates and intersecting said second plates at proximate extremities of each of said chambers;
  - 125 said plates having passage means connecting each of said nozzles with an associated one of said outlets; and
  - 130 a third plate contiguous with said second plate and including driver means for displacing ink in each of said chambers thereby causing the ejection of ink droplets from each of said nozzles.

According to another aspect of this invention, there is provided a method of making an impulse ink jet print head comprising the steps of:

(a) forming in a channel plate a pair of generally

5 coplanar axially aligned elongated chambers having relatively long sidewalls and relatively short endwalls and having outlets therefrom;

(b) positioning a diaphragm plate proximate to one side of the channel plate;

10 (c) securing a single sheet of transducer material to the diaphragm plate;

(d) removing a sufficient amount of the transducer material to leave discrete portions of the transducer material extending from the diaphragm so as to

15 overlie each of the chambers;

(e) forming a pair of spaced apart nozzles in a nozzle plate, each nozzle being perpendicular to a plane of the nozzle plate;

(f) positioning the nozzle plate proximate to a side

20 of the channel plate opposite the diaphragm plate; and

(g) assembling all of the plates so that they are held together in a superposed contiguous relationship with each of the nozzles being in communication

25 with an associated one of the chambers.

According to yet another aspect of this invention, there is provided a method of making an impulse ink jet print head comprising the steps of:

(a) forming in a channel plate a pair of generally

30 coplanar axially aligned elongated chambers having relatively long sidewalls and relatively short endwalls and having outlets therefrom;

(b) coating a layer of a diaphragm material onto a surface of a single sheet of a transducer material to

35 thereby form a diaphragm plate;

(c) positioning the diaphragm plate proximate to one side of the channel plate;

(d) removing a sufficient amount of the transducer material to leave discrete portions of the transducer

40 material extending from the diaphragm so as to overlie each of the chambers;

(e) forming a pair of spaced apart nozzles in a nozzle plate, each nozzle being perpendicular to a plane of the nozzle plate;

45 (f) positioning the nozzle plate proximate to a side of the channel plate opposite the diaphragm plate; and

(g) assembling all of the plates so that they are held together in a superposed contiguous relationship

50 with each of the nozzles being in communication with an associated one of the chambers.

The invention will now be described by way of example, reference being made to the accompanying drawings, in which:-

55 *Figure 1* is an exploded perspective view of a plurality of discrete plates employed in the construction of an ink jet print head embodying the present invention;

*Figure 2* is a side elevation view of the print head

60 illustrated in *Figure 1*;

*Figure 3* is a diagrammatic cross section view illustrating the flow of ink through a print head constructed in accordance with the present invention;

65 *Figure 4* is a top plan view of the print head

illustrated in *Figure 1*;

*Figure 5* is a detail top plan view illustrating, in enlarged form, a portion of *Figure 4* and specifically, the restrictor region;

70 *Figure 6* is a detail top plan view illustrating, in enlarged form, another portion of *Figure 4* and specifically, the nozzle region;

*Figure 7* is a cross sectional diagram illustrating a single sheet of a transducer material bonded to an ink jet array;

*Figure 8* is a cross sectional diagram illustrating a transducer array formed in accordance with the method of this invention including a plurality of discrete islands of the transducer material;

80 *Figure 9* is a cross sectional diagram illustrating a transducer array formed in accordance with an example of the method of the present invention having a plurality of discrete portions of transducer material without total penetration of the transducer

85 material; and

*Figure 10* is a cross sectional diagram illustrating a further embodiment of a transducer array formed by an example of the method of the present invention.

Primary goals sought to be achieved in the design

90 of an ink jet print head are reproducibility, high drop emission rate, ease of fabrication utilizing highly automated techniques, increased nozzle density, uniformity of performance among individual jets, and all of these with minimum cost. Such goals have

95 been achieved by the described embodiment of the present invention.

Referring initially to *Figure 1* which illustrates an ink jet print head 20 generally embodying the invention. Although *Figure 1* illustrates a 12 nozzle

100 print head, the concept of the invention can be reduced to a two nozzle configuration or can be extended to an n-nozzle array. That is, the concept of the invention can be employed for as many nozzles as described, subject to material and size limitations.

105 As illustrated in Figures 1 and 2, the print head 20 comprises a plurality of superposed, contiguous laminae or plates collectively represented by a reference numeral 22 (*Figure 2*). Each of the plates 22 is individually fabricated and has a particular

110 function as a component of the print head.

*Figure 3* is a diagrammatic representation provided for the purpose of illustrating the flow of ink through one nozzle of the print head 20, but is not intended to otherwise illustrate the relative

115 dimensions or operation of the print head 20 as shown in *Figure 1*.

As particularly seen in Figures 1 and 3, ink enters through a feed tube 24 and continues through the print head 20 as indicated by a series of discontinuous

120 arrowheads 26. The ink flows into a main chamber or manifold 28, then into a chamber 30 through a restrictor orifice 32, then to a nozzle 34 through which discrete ink droplets 36 are ejected. As the ink flows from the feed tube 24 to the manifold 28, it passes through aligned holes 38, 40, and 42 formed, respectively, in a diaphragm plate 44, a channel plate 46, and a restrictor plate 48.

Each of the two chambers formed in the channel plate 46 extends completely therethrough and can be

130 formed in a suitable manner as by etching. A typical

thickness for the channel plate is eight mils, but this dimension as with all of the other dimensions mentioned herein can vary considerably and still be within the scope of the invention. The roof of the chamber 30, which is the diaphragm plate 44, is typically 1 to 4 mils thick and has a transducer 50 composed of a suitable piezoceramic material described. Upon the application of an electrical field to the transducer 50, the diaphragm 44 is caused to bend into the chamber 30 thereby resulting in the displacement of the ink within the chamber. This results in ejection of a droplet from the nozzle and subsequent oscillation of the meniscus and refill of the chamber.

15 Two important resonant modes are associated with these motions, usually at approximately 10 to 24 kHz and 2 to 4 kHz, respectively. Provided the kinetic energy of the ink in the nozzle exceeds the surface energy of the meniscus at the nozzle 34, a droplet 36 is ejected. Sufficient energy is imparted to the droplet so it achieves a velocity of at least 2 m/sec. and thereby travels to a printing surface (not shown) proximate to the print head 20. The dimensions of the transducer 50, the diaphragm 44, the nozzle 34, the chamber 30 and the restrictor orifice 32 all influence the performance of the ink jet. Choice of these dimensions is coordinated with choice of an ink of a given viscosity. The shape of the electrical voltage pulse is also tailored to achieve the desired drop 25 velocity, refill time, and elimination of extraneous droplets, usually referred to as satellites. A preferred diameter of the nozzle 34 is 0.002 to 0.003 inches and the ratio of the length to width of the transducers 50, which are preferably rectangular in shape, is 30 approximately six to one.

In addition to those plates already named, the manifold 28 is formed in a manifold plate 52, the nozzle 34 is formed in a nozzle plate 54, and a base plate 56 is positioned intermediate the manifold plate 35 52 and the nozzle plate 54. The plates 22 comprising the print head 20 may be fabricated from stainless steel or some other alloy, or of glass, or of other suitably stiff but workable material. As appropriate, they may be held together by using adhesives, 40 brazing, diffusion bonding, electron beam welding or resistance welding.

As best illustrated in Figure 4, the individual chambers 30 are approximately rectangular, each having relatively long sidewalls 58 and relatively 45 short endwalls 60 and 62. A pair of chambers 30 is actually aligned along their major axes and is proximately opposed to one another at their respective endwalls 62. As illustrated, each of the opposed endwalls 62 extends towards the other of 50 the chambers 30 in an interlaced relationship and overlap a plane transverse to the channel plate 46 and containing axes of outlets 64 formed in the restrictor plate 48 and leading to the nozzles 34. Connector holes 66 and tapered holes 68 are formed 55 in the manifold plate 52 and in the base plate 56, respectively, to thereby connect each outlet 64 to an associated one of the nozzles 34. While the diameters of the outlets 64 and the connector holes 66 are approximately the same, about 12 to 16 mils in 60 diameter, each tapered hole 68 is tapered from a 12 to 65

16 mil diameter at its interface with the outlet 64 to a diameter of approximately two to three mils at its interface with the nozzle 34. Each set of outlets 64, connector holes 66, tapered holes 68, and nozzles 34 70 are preferably axially aligned, their axes being perpendicular, or at least transverse to, the plane of the manifold plate 52. The dimensions of the connector holes 66 and of the tapered holes 68 also influence the performance of the ink jet.

75 A plurality of pairs of the axially aligned chambers are formed in the channel plate 46 in side by side relationship along their respective sidewalls 58. While six such pairs of chambers 30 are illustrated in Figure 4 connected to 12 associated nozzles 34, it will 80 be appreciated that the arrangement described can be utilized for as few as two nozzles or as many as reasonably desired. By reason of the interlaced relationship of the endwalls 62 and their associated outlets 64 and nozzles 34, a high density of the 85 nozzles can be achieved while assuring the proper size of chamber 30 for the ejection of the droplets 36 from the nozzle 34. In a typical construction, the distance between centers of the nozzles is between .02 inches and .03 inches.

90 The restrictor plate 48 separates the chambers 30 from the ink supply manifolds 28. Whereas the diaphragm plate 44 serves as the roof for the chambers 30, the restrictor plate 48 serves as the undersurface of the chambers. A typical thickness for 95 the restrictor plate is 2 to 4 mils. The restrictor orifices 32 formed in a restrictor plate 48 are typically slightly smaller in diameter than the nozzles 34. This assures, upon actuating the transducer 50, greater flow of the ink through the nozzle 34 rather than back to the 100 manifold 28. It will be appreciated that in order for the individual nozzles 34 in an array such as that provided by the print head 20 to exhibit a minimum and acceptable variation in performance, it is necessary that the restrictors 32 also be of uniform 105 size. While the restrictor orifices 32 can be formed in a number of ways, such as by drilling or electroforming using masks, it has been found that greatest accuracy and uniformity is achieved by means of punching.

110 As in the instance of the chambers 30 formed in the channel plate 46, the manifolds 28 formed in the manifold plate 52 can be formed in a suitable manner as by etching and extend completely through the thickness of the plate, which is typically about 20 mils 115 thick. As seen in Figures 1 and 4, a pair of manifolds 28 are formed in the plate 52 and extend from relatively broad ends at which they are in communication with the feed tube 24 to narrowed regions having a plurality of dimpled portions 70, 120 each of which underlies an associated restrictor orifice 32. As seen particularly in Figures 1 and 3, the restrictor plate serves as the roof for the manifolds 28 and the manifold plate 22. In a similar manner, the base plate 56, which is typically about 20 mils thick, 125 serves as the undersurface for the manifolds 28 and to stiffen the structure of the print head.

There may also be instances in which it is desirable to completely eliminate the base plate 56. In such an event, the orifice plate would serve as the 130 undersurface for the manifolds 28 and the outlet

connector holes 66 would be tapered in the manner of the tapered holes 68.

The nozzle plate 54, as best seen in Figure 1, is formed with a row of nozzles 34 therein aligned with 5 the outlets 64, connector holes 66, and tapered holes 68 when the print head 20 is fully assembled. While the nozzles 34 can be formed according to a number of suitable techniques, punching is a preferred technique for insuring uniformity as well as accuracy 10 within close tolerance limitations. The operation of the print head in ejecting the droplets 36 may be further improved by tapering the nozzles 34 as well as the tapered holes 68.

Referring now to Figures 1 and 7, a transducer array 72 comprising a plurality of the individual transducers 50 utilized in the impulse ink jet print head may be produced in accordance with the present invention by starting with a single sheet of transducer material, preferably and hereinafter 15 referred to, as a piezoceramic material 74. In one embodiment the single sheet of piezoceramic material 74 is bonded by an adhesive layer 76, preferably composed of an epoxy or low temperature solder, to the diaphragm plate 44 in 20 direct contact over the area of ink 78 in each of the compression chambers 30. The adhesive employed in this embodiment of the present invention to bond the piezoceramic material to the diaphragm should 25 preferably be applied so as to be uniform in thickness, have a high Young's modulus and assure 30 consistent electrical contact between the diaphragm and the piezoceramic material. The thickness of the diaphragm material ranges between 0.001 and 0.005 inches. However, when non-conducting adhesives 35 are employed, there must be intimate contact between portions of the diaphragm and portions and portions of the transducer material to assure 40 electrical continuity with the adhesive material filling the remaining interstices. In any event, the diaphragm has a comparable stiffness to the piezoceramic material.

In accordance with the present invention, a permanent polarization of the piezoceramic material 74 is preferably carried out prior to bonding this 45 material to the diaphragm plate 44, i.e., poling of the piezoceramic material. The poling process can be achieved by applying a d.c. voltage to the piezoceramic material in excess of the saturation field of the piezoceramic material, i.e., 65–100 50 volts/mil.

Thereafter a sufficient amount of the piezoceramic material 74 is removed to form a plurality of discrete portions of the piezoceramic material extending from the diaphragm plate. In the impulse ink jet print 55 head 20 these discrete portions, the resulting individual transducers 50, are positioned over the chambers 30. In accordance with the present invention the amount and location of the piezoceramic material (including adhesive) that is 60 removed can vary, and thereby result in different configurations for the transducer array 72. For example, and as shown in Figure 8, a sufficient amount of piezoceramic material 74 is removed to 65 form a plurality of discrete islands, i.e. individual transducers 50, of piezoceramic material bonded to

the diaphragm plate 44 in areas directly over each associated chamber 30.

During the process of removing piezoceramic material, care must be taken to avoid even slightly 70 damaging the diaphragm which may be as thin as 0.001 inches. One way to minimize the chances of harming the diaphragm, is to avoid completely penetrating the piezoceramic material during the removal procedure. As shown in Figure 9, this can be 75 accomplished by removing only a sufficient amount of piezoceramic material to form a plurality of discrete portions 80 of piezoceramic material without totally penetrating the thickness of this material. Once again, these discrete portions 80 are formed in 80 an area directly over the associated chambers. The stiffness of the remaining piezoceramic material over the ink chambers 30 where the processing of the ink occurs is not enough to affect the bending of the transducer and diaphragm materials, and therefore 85 not enough to affect the displacement needed to drive the ink 78 out of its chamber 30 and through the nozzle 34 of the ink jet print head 20.

In many instances it may be preferred to mechanically strengthen the islands or discrete 90 portions of piezoceramic material that is left after the process step of removing the transducer material for the purpose of decreasing the chances of having these transducer portions fail due to fracturing or fatigue. This is accomplished in accordance with the 95 present invention and as shown in Figure 10, by providing a smooth mechanical transition 82 at the boundary between a remaining portion 84 of the piezoceramic material and the diaphragm plate 44.

According to the method just described, a single 100 sheet of transducer material is bonded to a diaphragm plate using an adhesive. If the adhesive could be eliminated, it would be possible to increase energy transfer since the adhesive layer can absorb mechanical energy. Another problem area that 105 would thereby be avoided involves the failure of the adhesive layer to be penetrated so that electrical contact with the diaphragm plate is achieved. The resulting capacitive layer will diminish the electrical field in the piezoceramic, thus reducing the bending 110 effect.

Accordingly, viewing again Figure 7, in a preferred embodiment the single sheet of piezoceramic material 74 is first coated with a diaphragm material without the presence of the adhesive layer 76. As in 115 the previous embodiment, the resulting diaphragm plate 44 is then incorporated into the ink jet print head 20 so as to be in direct contact over the area of the ink 28 in each of the chambers 30. The diaphragm plate 44 can be, for example, a metal or alloy and may 120 be as thin as 0.001 inches. In any event, the diaphragm plate is preferably formed of a material having a comparable stiffness to the piezoceramic material to thereby enable both the diaphragm and the piezoceramic material to bend when the 125 transducer expands or contracts due to an applied voltage. The coating step is preferably achieved by electrodepositing a diaphragm material on one face of the piezoceramic sheet. The surface of the piezoceramic sheet should have a flash of a material 130 which will enable the efficient electroplating of a

metal (e.g., nickel) onto the piezoceramic material.

The removal of transducer material to form any of the above described examples of discrete portions of transducer material as illustrated in Figures 8

- 5 through 10 can, in accordance with the present invention be accomplished by a variety of procedures. For example, one procedure that can be used involves chemical etching. Various types of acid solutions (e.g., solutions containing
- 10 hydrofluoric acid, phosphoric acid, fluoroboric acid, sulphuric acid, nitric acid or hydrochloric acid) can be used to dissolve most of the piezoceramic matrix. Any residue can be rinsed or otherwise mechanically removed. To obtain a specific etch pattern, a mask
- 15 may be formed by uniformly coating the piezoceramic with a polymer such as a photoresist and selectively dissolving sections of the polymer after ultraviolet light exposure through a photographically prepared mask. The remaining
- 20 polymer is unaffected by the etchant used to dissolve the piezoceramic material. After removal of the unwanted piezoceramic, the remaining photoresist is dissolved. The specific depth of the chemical etch is determined by exposure time, temperature,
- 25 concentration of the etchant and mechanical agitation. Using, for example, a piezoceramic material formed of a mixture of PbO, ZrO<sub>2</sub>, TiO<sub>2</sub> and dopants, chemical etching to form discrete portions of piezoceramic material in accordance with the
- 30 present invention has been accomplished with an acid solution of 10 ml. of HC1 (specific gravity 1.19) and 3 ml. of HF (40%, solution) at room temperature for periods of time up to about 3 hours. Another process for removing piezoceramic material is laser
- 35 scribing wherein continuous or pulsed lasers may be used to vaporize the unwanted sections of piezoceramic. The laser or the piezoceramic transducer is positioned mechanically under the control of the preprogrammed microprocessor.
- 40 Many factors affect the ablation rate including laser output, atmosphere, focusing of laser, exposure time, gas assist, heat dissipation mechanisms, refractory nature of the specific piezoceramic, the effective emissivity of the
- 45 piezoceramic, and the absorption of light. Care must be taken not to thermally stress the piezoceramic adjacent to the ablated region. Transducer arrays were made in accordance with this technique using a laser scribing procedure in which (a) Nd:YAG lasers
- 50 were used; (b) both a continuous wave mode and a high frequency pulse (e.g., 5–10 kHz) modes were employed; (c) a scan speed of about 3 inches/sec. was used; (d) the procedure was tried with and without an aperture; and (e) both single and multiple
- 55 passes were employed. Another technique that can be used for removing piezoceramic material is use of an abrasive gas jet which is computer controlled. In this technique, a stream of fine particles (e.g., alumina) is shot through a tiny nozzle with high
- 60 pressure gas to abrade away piezoceramic material in a controlled fashion. This technique is preferred because it is dry and introduces the least number of defects into the piezoceramic material. As with a laser, the cutting location is determined
- 65 mechanically. Control parameters include exposure

time, speed and density of particles, particle type, standoff distance, and the details of particle flow.

Still other techniques that can be used for removing the transducer material in accordance with 70 the present invention include ultrasonic machining and saw cutting in which a diamond saw with a narrow kerf, such as used to dice silicon wafers, can cut out sections of the piezoceramic material. The saw cutting technique is generally limited to straight 75 line cuts. Ultrasonic machining employs a slurry of fine abrasive, such as for example, 600 grit boron carbide. The tool used can have any pattern, e.g. circles, rectangles, etc. The cutting tool vibrates over a small amplitude at high frequency, typically 20 kHz.

80 The cutting motion can be precisely controlled and produces little force on the workpiece. Thus, very thin sheets of transducer material can be gently machined to close tolerance.

Thus, the embodiment disclosed herein, provides 85 for a greatly simplified design of an ink jet print head utilizing a plurality of plates or laminae resulting in ease of fabrication, while preserving uniformity of sizes for the restrictor orifices and nozzles as well as increased nozzle density by reason of the interlacing 90 arrangement of the nozzles and their associated chambers. Emphasis also has been placed on the advantages of the accuracy of formation, ease of manufacture, and reproducibility of the transducers utilized with the print head of the invention.

95 While the preferred embodiments of the invention have been disclosed in detail, it should be understood by those skilled in the art that various modifications may be made to the illustrated embodiments without departing from the scope of 100 the invention.

In the above description there is disclosed an improved impulse ink jet print head and a method of fabricating such an improved print head. It comprises a plurality of superposed, contiguous 105 plates including a nozzle plate with at least a pair of nozzles for ejecting ink droplets in a direction perpendicular to a plane of the plates. Another plate is a channel plate defining at least a pair of coplanar axially aligned elongated chambers, each connected 110 to a ink supply and having an outlet communicating with an associated nozzle. A diaphragm plate overlies the channel plate and has transducers thereon for imparting a displacement of ink from each of the chambers to eject discrete ink droplets 115 from the nozzles. Other plates may include a manifold plate for directing ink to a plurality of pairs of chambers and a restrictor plate with restrictor orifices positioned between the ink supply and each of the chambers. The method of fabricating the print 120 head includes forming the different plates, forming the transducers, and assembling all of the components in a particular relationship.

In short, it can be said that the described embodiment of the present invention exhibits an

advantage over the Kyser et al patents discussed in the introduction to the specification by providing a print head of significantly improved compactness and reduced number of parts and over the recently 5 issued Koto patent by providing a print head requiring a smaller number of parts.

It is believed that the described embodiments may overcome many of the disadvantages of the various constructions and methods of manufacturing

10 impulse ink jet print heads disclosed by the prior art.

In the described embodiment, the nozzle array is of laminated construction in which each of the plates, performs one or more functions. In the embodiment, the laminae or plates are, variously, a diaphragm 15 plate, a channel plate, a restrictor plate, a manifold plate, a base plate, and an orifice plate, or multiples of these.

In the described embodiment, a plurality of pairs of generally coplanar axially aligned elongated 20 chambers have relatively long sidewalls and relatively short endwalls and the short endwalls have outlets communicating with nozzles that are proximately opposed to one another at their endwalls; further, each of the opposed endwalls 25 extends toward the other of the chambers in an interlaced relationship and overlaps a plane transverse to the plane of the laminae or plates and containing axes of the outlets therein.

There is described a method of manufacturing an 30 impulse ink jet print head that is less expensive than prior art methods, specifically, a method requiring fewer parts, fewer assembly steps, and therefore considerably less time to produce.

There is disclosed a method of manufacturing a 35 transducer array that employs a single sheet of transducer material and thereby avoids the necessity of separately bonding individual transducers to form the transducer array.

In the disclosed method of manufacturing a 40 transducer array the transducers themselves are more uniform dimensionally and compositionally than those disclosed in the prior art, thereby resulting in much lower variations in the required drive voltages for each of the transducers.

45 In the disclosed method control of the location of each of the transducers to within a few ten thousandths of an inch is attainable; whereas, with the prior art method of placing a large number of tiny transducers individually, errors on the order of plus 50 or minus 0.0005 inches can be expected.

It is believed that the disclosed method of manufacturing a transducer array substantially avoids the prior art problem of breakage of the extremely fragile transducers; breakage is much 55 more likely, unless extraordinary precautions are taken, when handling many small pieces instead of a single sheet of transducer material. Similarly it is believed that the disclosed method substantially avoids the formation of internal microscopic 60 fractures in the transducers which can lead to premature failure.

In the disclosed method which can be cut from a flat sheet of material, thereby enabling optimization of output of an ink jet print head as well as

65 compensation for ink channels having different

lengths.

There is disclosed an improved method of making a transducer array for use in an impulse ink jet print head from a single sheet of transducer material

70 comprising the steps of securing a single sheet of transducer material to a diaphragm and removing a sufficient amount of the transducer material to leave a plurality of discrete portions of the transducer material extending from the diaphragm.

75 Furthermore there is disclosed a method of making a transducer array for use in an impulse ink jet print head from a single sheet of transducer material comprising the steps of coating a layer of a diaphragm material onto a single sheet of a transducer material and removing a sufficient 80 amount of the transducer material to leave a plurality of discrete portions of the transducer material extending from the diaphragm.

## 85 CLAIMS

1. An impulse ink jet print head comprising: a plurality of operating plates held together in a superposed relationship including at least:

90 a first plate including a pair of nozzles therein for ejecting droplets of ink therethrough; a second plate defining a pair of generally coplanar axially aligned elongated ink chambers having relatively long sidewalls and relatively short 95 endwalls, each of said chambers connected to an ink supply and having an outlet for directing ink toward an associated one of said nozzles in said first plate; each of said nozzles having a central axis

extending transversely of the planes of said plates 100 and intersecting said second plates at proximate extremities of each of said chambers; said plates having passage means connecting each of said nozzles with an associated one of said outlets; and

105 a third plate contiguous with said second plate and including driver means for displacing ink in each of said chambers thereby causing the ejection of ink droplets from each of said nozzles.

2. An impulse ink jet print head as claimed in 110 Claim 1 wherein said plurality of operating plates includes:

a fourth plate contiguous with said second plate having a pair of restrictor orifices therein, each of said restrictor orifices positioned intermediate the

115 ink supply and an associated one of said chambers, each of said restrictor orifices being smaller in size than each of said nozzles.

3. An impulse ink jet print head as claimed in claim 1 or claim 2 wherein said chambers are axially 120 aligned along their major axes and proximately opposed to one another at their said endwalls, each of said opposed endwalls extending toward the other of said chambers in an interlaced relationship and overlapping a plane transverse to said second plate

125 and containing axes of the outlets from said chambers and axes of both of said nozzles.

4. An impulse ink jet print head as claimed in Claim 3 wherein the transverse plane is perpendicular to the major axes of said chambers.

130 5. An impulse ink jet print head as claimed in any

one of the preceding claims wherein said outlets and their associated said nozzles are aligned on an axis perpendicular to the plane of said chambers.

6. An impulse ink jet print head comprising:

- 5 a plurality of operating plates including at least:
  - a first plate including a plurality of nozzles therein for ejecting droplets of ink therethrough;
  - a second plate defining a plurality of pairs of generally coplanar axially aligned elongated chambers having relatively long sidewalls and relatively short endwalls, pairs of said chambers being in side by side relationship along their respective said sidewalls;
  - each of said chambers connected to an ink supply
  - 15 and having an outlet for directing it toward an associated one of said nozzles in said first plate; each of said nozzles having a central axis extending transversely to the planes of said plates and intersecting said second plates at proximate extremities of each of said chambers;
  - said plates having passage means connecting each of said nozzles with an associated one of said outlets;
  - a third plate proximate to said second plate and including drive means for displacing ink in each of said chambers thereby causing the ejection of ink droplets from each of said nozzles.
- 7. An impulse ink jet print head as claimed in Claim 6 wherein said chambers are generally rectangular in shape and wherein said driver means includes a generally rectangular piezoceramic transducer fixed on said third plate so as to be generally coextensive with each of said chambers.
- 8. An impulse ink jet head as claimed in claim 6 or claim 7 wherein said plurality of operating plates includes:
  - a fourth plate contiguous with said second plate having a pair of restrictor orifices therein, each of said restrictor orifices positioned intermediate the ink supply and an associated one of said chambers, each of said restrictor orifices being similar in size to each of said nozzles.
- 9. An impulse ink jet print head as claimed in claim 8 wherein a matched pair of said chambers is axially aligned along their major axes and proximately opposed to one another at their said endwalls, each of said opposed endwalls extending toward the other of said chambers in an interlaced relationship and overlapping a plane transverse to said second plate and containing axes of the outlets from said chambers and axes of both of said nozzles.
- 10. An impulse ink jet print head as claimed in claim 8 wherein said plurality of operating plates includes:
  - 55 a fifth plate having a pair of manifolds therein connected to an ink supply; said chambers being arranged in two parallel rows, one of said rows located to one side of said transverse plane, the other of said rows located to the opposite side of said plane;
  - 60 one of said manifolds connected to said restrictor orifices located to one side of said transverse plane, the other of said manifolds connected to said restrictor orifices located to the other side of said transverse plane.

11. An impulse ink jet printing head as claimed in Claim 8 wherein the axes of said restrictor orifices, of said outlets, and of said nozzles are all perpendicular to the plane of said chambers.

- 70 12. A method of making an impulse ink jet print head comprising the steps of:
  - (a) forming in a channel plate a pair of generally coplanar axially aligned elongated chambers having relatively long sidewalls and relatively short endwalls and having outlets therefrom;
  - (b) positioning a diaphragm plate proximate to one side of the channel plate;
  - (c) securing a single sheet of transducer material to the diaphragm plate;
  - (d) removing a sufficient amount of the transducer material to leave discrete portions of the transducer material extending from the diaphragm so as to overlie each of the chambers;
  - (e) forming a pair of spaced apart nozzles in a nozzle plate, each nozzle being perpendicular to a plane of the nozzle plate;
  - (f) positioning the nozzle plate proximate to a side of the channel plate opposite the diaphragm plate; and
- 80 13. A method as claimed in Claim 12 wherein the diaphragm is formed of a material having a stiffness comparable to said transducer material.
- 85 14. A method as claimed in claim 12 or claim 13 wherein step (d) is achieved by a chemical etching process.
- 90 15. A method as claimed in claim 12 or claim 13 wherein step (d) is achieved by a laser scribing process.
- 95 16. A method as claimed in claim 12 or claim 13 wherein step (d) is achieved by an abrasive gas jet process.
- 100 17. A method as claimed in claim 12 or claim 13 wherein step (d) is achieved by an ultrasonic machining process.
- 105 18. A method as claimed in claim 12 or claim 13 wherein step (d) is achieved by a saw cutting process.
- 110 19. A method as claimed in any one of claims 12 to 18, wherein said transducer material is a piezoceramic material.
- 115 20. A method as claimed in any one of claims 12 to 19, wherein step (a) includes the step of:
  - (h) forming the pair of chambers such that they are axially aligned along their major axes and proximately opposed to one another at their endwalls, each of the opposed endwalls extending toward the other of the chambers in an interlaced relationship and overlapping a plane transverse to the plane of the second plate and containing axes of the outlets.
- 120 21. A method of making an impulse ink jet print head comprising the steps of:
  - (a) forming in a channel plate a pair of generally coplanar axially aligned elongated chambers having relatively long sidewalls and relatively short endwalls and having outlets therefrom;
- 125 130

- (b) coating a layer of a diaphragm material onto a surface of a single sheet of a transducer material to thereby form a diaphragm plate;
- (c) positioning the diaphragm plate proximate to one side of the channel plate;
- 5 (d) removing a sufficient amount of the transducer material to leave discrete portions of the transducer material extending from the diaphragm so as to overlie each of the chambers;
- 10 (e) forming a pair of spaced apart nozzles in a nozzle plate, each nozzle being perpendicular to a plane of the nozzle plate;
- (f) positioning the nozzle plate proximate to a side of the channel plate opposite the diaphragm plate;
- 15 and
- (g) assembling all of the plates so that they are held together in a superposed contiguous relationship with each of the nozzles being in communication with an associated one of the chambers.
- 20 22. A method as claimed in Claim 21 wherein the diaphragm is formed of a material having a stiffness comparable to said transducer material to enable both the diaphragm and the transducer to bend when the transducer contracts or expands.
- 25 23. A method as claimed in claim 21 or claim 22 wherein step (d) is achieved by a chemical etching process.
24. A method as claimed in claim 21 or claim 22 wherein step (d) is achieved by a laser scribing process.
- 30 25. A method as claimed in claim 21 or claim 22 wherein step (d) is achieved by an abrasive gas jet process.
26. A method as claimed in claim 21 or claim 22
- 35 wherein step (d) is achieved by an ultrasonic machining process.
27. A method as claimed in claim 21 or claim 22 wherein step (d) is achieved by a saw cutting process.
- 40 28. A method as claimed in any one of claims 21 to 27 wherein said transducer material is a piezoceramic material.
29. An impulse ink jet print head substantially as hereinbefore described with reference to the
- 45 accompanying drawings.
30. A method of making an impulse ink jet print head substantially as hereinbefore described with reference to the accompanying drawings.
31. All and any novel features or combinations
- 50 thereof disclosed herein.